

SPECIFICATION

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CLOSE PACKING LED ASSEMBLY WITH VERSATILE INTERCONNECT ARCHITECTURE

Background of Invention

[0001] The invention relates to the electronic and optoelectronic arts. It is especially applicable to the packaging of light emitting diodes (LED's), and will be described with particular reference thereto. However, the invention will also find application in the packaging other electronic and optoelectronic devices, such as photodetectors, signal receivers, vertical cavity surface emitting lasers (VCSEL's), photovoltaic devices, and the like.

[0002] Light emitting diodes (LED's) find application in fiber optical communications, lighting applications, display applications, and other applications where a compact, low voltage, rugged, and high efficiency light source is advantageous. In many LED applications, a plurality of LED's are advantageously arranged into an array or other pre-determined arrangement comprising similar or dissimilar LED types. In lighting or display applications, LED's emitting in the red, green, and blue regions are preferably closely packed to form a color "pixel" that blends the three colors. In this manner white light can be generated. Alternatively, by selectively varying the optical output intensity of the three colored LED's, a selected color can be generated. An array of such "pixels" can form a color display or an illuminating surface emitting white light, among other applications.

[0003] The prior art includes fabrication of LED arrays on-chip. In this approach, semiconductor layers comprising the LED's are generated on a substrate, usually a semiconductor substrate, and individual LED's of the array are isolated by etching mesas in the LED layers. This approach is limited in application. The LED's are typically

required to be all of one type. The choice of substrate is limited to those compatible with the semiconductor layer generation method. Many commercial LED's are formed from III-V compound semiconductor layers, and the substrates which are used for the growth of such layers, typically including GaAs and InP wafers, sapphire substrates, and the like, are often expensive, fragile, and of limited lateral area.

[0004] A much more flexible approach is to fabricate discrete LED's using any convenient method, and then to bond the discrete LED's to a host substrate to form the LED arrangement thereon. In this manner dissimilar LED's, such as red, green, and blue LED's comprised of different material layers, can be advantageously combined. The choice of substrate is greatly expanded. However, the individual LED's are electrically isolated, so that intricate wire bonding or other electrical interconnecting methods are typically applied to complete the array. Additionally, a different host substrate shape and electrical interconnect pattern is needed for each distinct LED arrangement, which limits the standardization of parts and complicates array manufacturing.

[0005] The present invention contemplates an improved modular mounting assembly for forming arrays of LED's and other components.

Summary of Invention

[0006] In accordance with one embodiment of the present invention, a mounting structure for assembling a plurality of optoelectronic components is disclosed. A first substrate has at least one first optoelectronic component arranged thereon. The first substrate is in the shape of a rhombus and has an edge connector disposed on an edge thereof. A second substrate has at least one second optoelectronic component arranged thereon. The second substrate is in the shape of a rhombus and has an edge connector disposed on an edge thereof which operatively connects with the edge connector of the first substrate to form an arrangement of the at least one first optoelectronic component and the at least one second optoelectronic component.

[0007] In accordance with another aspect of the present invention, at least one of the first substrate and the second substrate has a rhombus shape that corresponds to a primitive unit cell of a hexagon.

[0008] In accordance with another aspect of the present invention, an interconnecting

element connects with the edge connector of the first substrate and with the edge connector of the second substrate to connect the edge connector of the first substrate with the edge connector of the second element.

[0009] In accordance with another aspect of the present invention, the first substrate includes an electrical connection between the at least one first component and the edge connector of the first substrate. The second substrate includes an electrical connection between the at least one second component and the edge connector of the second substrate. The interconnecting element electrically connects the edge connector of the first substrate with the edge connector of the second substrate to form an electrical arrangement of the at least one first component and the at least one second component.

[0010] In accordance with another aspect of the present invention, the first substrate includes a thermally conductive layer, and a printed circuit board into which the edge connector is formed. The printed circuit board includes an electrical path connecting the at least one first optoelectronic component with the edge connector.

[0011] In accordance with another aspect of the present invention, the at least one first optoelectronic component includes at least one light emitting diode (LED). The first substrate includes a lens in operative communication with the at least one LED.

[0012] In accordance with another aspect of the present invention, the at least one first optoelectronic component includes a plurality of light emitting diodes (LED's) disposed on the substrate. The printed circuit board includes an electrical path that electrically interconnects the LED's disposed on the substrate.

[0013] In accordance with another aspect of the present invention, the thermally conductive layer has depressions in which the LED's are arranged, and the printed circuit board has holes arranged to allow the LED light emission to pass through.

[0014] In accordance with another aspect of the present invention, a third substrate has at least one third component arranged thereon. The third substrate is in the shape of a rhombus and has a first edge connector disposed on an edge thereof which operatively connects with a second edge connector of the first substrate. The third substrate also has a second edge connector disposed on an edge thereof which

operatively connects with a second edge connector of the second substrate. The first, second, and third rhombus-shaped substrates are arranged to form a hexagonally shaped mounting structure.

[0015] In accordance with another aspect of the present invention, at least one terminating element completes an electrical circuit.

[0016] In accordance with another aspect of the present invention, at least one terminating element supplies electrical power to the mounting structure.

[0017] In accordance with another embodiment of the present invention, a modular mounting assembly for connecting a plurality of light emitting diodes (LED's) in a selectable electrical and spatial arrangement is disclosed. A plurality of substrates are provided. Each substrate has at least one LED fixedly arranged thereon, and a plurality of connectors arranged thereon that are in electrical communication with the at least one LED. The plurality of substrates are arranged in a spatial arrangement having selected pairs of connectors in electrical communication with each other providing an electrical arrangement between the plurality of LED's.

[0018] In accordance with another aspect of the present invention, an interconnecting element electrically and structurally interconnects selected substrates through pairs of connectors. For example, an interconnecting element cooperates with the selected substrates to form one of a series LED electrical interconnection and a parallel LED electrical interconnection.

[0019] In accordance with another aspect of the present invention, at least one of the plurality of substrates has a rhombic shape.

[0020] In accordance with yet another embodiment of the present invention, an extensible LED structure is disclosed. An LED is supported by a rhomboidal shaped substrate. At least one electrical socket is disposed on the rhomboidal shaped substrate and shaped to receive an electrical plug. The electrical socket provides electrical communication to the LED.

[0021] In accordance with another aspect of the present invention, a discrete plug mechanically connects the electrical socket to an electrical socket disposed on a

second substrate.

[0022] In accordance with another aspect of the present invention, a plug is integral with the substrate. The plug is mechanically connectable to an electrical socket disposed on a second substrate.

[0023] In accordance with another aspect of the present invention, the plug comprises electrical paths and when the plug is seated in the socket, the electrical paths place the LED in a predetermined electrical relationship with an LED on the second substrate.

[0024] The advantages and benefits of the present invention will become apparent to those of ordinary skill in the art upon reading and understanding the following detailed description.

Brief Description of Drawings

[0025] The invention may take form in various components and arrangements of components, and in various steps and arrangements of steps. The drawings are only for purposes of illustrating a preferred embodiment and are not to be construed as limiting the invention.

[0026] FIGURE 7 shows an exemplary array of twelve rhombic substrates forming a hexagonal array of twenty-four components.

[0027] FIGURE 2 shows the geometry of an exemplary rhombic substrate.

[0028] FIGURE 3 shows a first embodiment of the invention, having two LED components connected electrically in series on a rhombic substrate.

[0029] FIGURE 4 shows a sectional view of the embodiment of FIGURE 3 taken along the Section S-S.

[0030] FIGURE 5 shows an electrical schematic of the substrate of FIGURE 3.

[0031] FIGURE 6 shows an exemplary interconnecting element that is compatible with the substrate of FIGURES 3 and 5.

[0032] FIGURE 7 shows an exploded view of an exemplary interconnection of three

rhombic substrates corresponding to the embodiment of FIGURES 3 and 5.

[0033] FIGURE 8A shows an electrical schematic of a series connection of two substrates corresponding to the substrate embodiment of FIGURES 3 and 5.

[0034] FIGURE 8B shows an exemplary interconnecting element that implements the series interconnection shown in FIGURE 8A.

[0035] FIGURE 9A shows an electrical schematic of a parallel connection of two substrates corresponding to the substrate embodiment of FIGURES 3 and 5.

[0036] FIGURE 9B shows an exemplary interconnecting element that implements the parallel interconnection shown in FIGURE 8A.

[0037] FIGURE 10A shows an electrical schematic of a terminating element that connects the cathode of the last substrate according to the substrate embodiment of FIGURES 3 and 5 to circuit ground.

[0038] FIGURE 10B shows an exemplary interconnecting element that implements the circuit termination shown in FIGURE 10A.

[0039] FIGURE 11A shows an electrical schematic of a terminating element that connects a substrate of the type shown in FIGURES 3 and 5 to a voltage source.

[0040] FIGURE 11B shows an exemplary interconnecting element that implements the voltage connection shown in FIGURE 11A.

[0041] FIGURE 12 shows an exemplary series interconnection of three substrates of the type shown in FIGURES 3 and 5 using appropriate interconnecting and terminating elements.

[0042] FIGURE 13 shows a second embodiment of the invention, having two sets of red, green, and blue LED components that provides independent electrical access to the three colors.

[0043] FIGURE 14 shows an electrical schematic of the substrate of FIGURE 13.

[0044] FIGURE 15 shows a third embodiment of the invention that includes a connector appropriate for connection to a connecting cable.

[0045] FIGURE 16 shows an exemplary arrangement of several substrates of the type shown in FIGURE 15 on an interconnecting cable.

Detailed Description

[0046] With reference to FIGURES 1 and 2, a modular mounting assembly 10 is described. A plurality of substrates 12 each have one or more components 14 arranged thereon. In the illustrated embodiment of FIGURE 1, each substrate 12 has two LED components 14 arranged thereon. The plurality of substrates 12 are arranged in a selected manner to form the mounting assembly 10 that arranges the components 14 in a selected arrangement, such as the hexagonal arrangement of FIGURE 1 comprised of twelve substrates 12 and twenty four LED components 14.

[0047] In one embodiment shown in FIGURES 1 and 2, each substrate 12 has the shape of a rhombus, i.e. a parallelogram having four sides of essentially equal length L , with oppositely oriented angles equal. Thus, a rhombus can be specified by two angular parameters α and β , along with the side length L , as shown in FIGURE 2. In the illustrated embodiment of FIGURE 1, the angles α and β are 60° and 120° , respectively, so that each rhombic substrate 12 corresponds to a primitive unit cell of a hexagon, thus enabling particularly close packing of the components 14 such as in the assembly 10 shown in FIGURE 1. Hexagonal symmetry is particularly advantageous because hexagons can be arranged to form densely packed two-dimensional arrays. Hexagonal symmetry also can be used to create three-dimensional structures such as spheres or geodesic-type domes.

[0048] In another embodiment (not shown), $\alpha = \beta = 90^\circ$ so that a square unit cell substrate results. It will be appreciated that the rhombic shape provides a high degree of symmetry that enables arrangement of a plurality of rhombic substrates 12 into a wide range of selected spatial arrangements. Of course, other values for the angles α and β can also be used within the geometrical limitation that $\alpha + \beta = 180^\circ$ for the rhombic geometry shown in FIGURE 2.

[0049] With continuing reference to FIGURE 1, each substrate 12 includes one or more connectors 16 that effectuate interconnection of the substrates 12. In one embodiment, the connectors 16 also cooperate to effectuate electrical interconnection

of the components 14 across the boundaries of paired substrates 12.

[0050] With reference now to FIGURES 3 and 4, the substrate 12 is described. Each substrate 12 has two LED components 14a and 14b arranged thereon. The LED's 14a, 14b can be similar LED's, e.g. two similar LED components that both emit white light. Alternatively, the LED's 14a, 14b can be dissimilar LED components, e.g. LED's of different colors, different intensities, different angular distributions, etc.

[0051] With particular reference now to FIGURE 4, which shows a sectional view taken along the Section S-S shown in FIGURE 3, the substrate 12 includes a thermally conductive layer 20, such as a copper plate. In an exemplary embodiment a copper plate about 0.3 cm thick is used. Each LED component arranged on the substrate 12, e.g. the exemplary LED 14a is disposed in a receiving depression 22 of the copper plate 20. The receiving depression 22 is a conical well with a flat bottom. The mounting of an LED die therein can employ thermally conductive cement, a resin, an epoxy, or the like, as is well known to those of ordinary skill in the art. The thermally conductive layer 20 provides heat sinking for the LED components 14a, 14b. However, the LED components 14a, 14b are advantageously electrically isolated from the copper plate 20.

[0052] An insulating layer such as a printed circuit board (PC board) 24 is affixed to the thermally conductive layer 20. The PC board 24 has one or more openings or holes 26 corresponding to the receiving wells 22 of the copper plate 20, through which the LED light emission passes during LED operation. The substrate 12 optionally includes additional optical components, such as a transparent cover plate 30 and a lens 32 that is in operative communication with the LED 14a.

[0053] With continuing reference to FIGURES 3 and 4, the PC board 24 advantageously facilitates electrical connections to the components. A plurality of PC board traces connect the LED's 14a, 14b to the connectors 16 and optionally also connect the LED's 14a, 14b to each another. For example, a trace 40 can be used to interconnect the LED's 14a, 14b electrically in series. The electrodes (not shown) of the LED components 14 are connected to the PC board traces 40 using wire bonds or other means (not shown) that are well known to those of ordinary skill in the art. In one embodiment, the connectors 16 are formed into the edges of the PC board 24 so that

the traces advantageously directly connect to the electrical conductor members comprising the connectors 16, and the connectors 16 are readily accessible at the edges of the substrate 12. In the illustrated exemplary embodiment of FIGURE 3, there are four connectors 16, and each connector has five conductor members 1, 2, 3, 4, and 5.

[0054] With reference now to FIGURE 5, an electrical circuit schematic is shown corresponding to the exemplary substrate 12 of FIGURES 3 and 4. In the illustrated exemplary embodiment of FIGURE 5, the LED's 14a, 14b are connected in series on the substrate 12. The anode 44 and the cathode 46 of the series LED combination 14a, 14b are accessible at connector conductor members 1 and 5, respectively. Although only two of the five conductor members are directly connected to the components in the exemplary substrate 12, it will be appreciated that providing additional conductor members, e.g. unattached members 2, 3, and 4 advantageously facilitates adding additional components, such as additional LED's, to the substrate 12 and enhances the modularity of the system. Additionally, at least one conductor member is reserved as a circuit ground. In the exemplary embodiment of FIGURES 3 and 5, conductor member 4 is reserved as the ground conductor. Of course, it will also be recognized that other conductor designations can be made, and additionally more or fewer than five conductor members can be included on each connector 16. However, for a given modular mounting assembly some standardization of the number and designations of the conductors is highly advantageous.

[0055] With reference now to FIGURES 6 and 7, an approach for effectuating the interconnection of pairs of connectors 16 is described. An interconnecting element 50A of a type "A" operatively connects to a pair of connectors 16 at mating ports 52 and 54 of the interconnecting element 50A. The interconnecting element 50A mechanically connects to the two substrates 12 that have the pair of connectors 16 to effectuate structural interconnection between the two substrates 12. The mechanical connection can be by a frictional fit (not shown) or by fastenings 56 which can be screws, rivets, or the like. The interconnecting element 50A also has a pre-selected electrical configuration that effectuates a desired electrical arrangement of the components of the connected substrates 12, such as a series connection arrangement, parallel connection arrangement, or the like. As can be seen in FIGURE

6, the two mating ports 52, 54 each have five electrical connector members 1', 2', 3', 4', 5' that correspond to and electrically connect with the connector members 1, 2, 3, 4, 5 of the connectors 16 of the substrates 12. The pre-selected electrical configuration is determined by the electrical interconnections of the two ports 52, 54 inside the interconnecting element 50A (not shown in FIGURE 6). Thus, as shown in FIGURE 7, two interconnecting elements 50A of type "A" that has a particular electrical configuration are used in conjunction with a third interconnecting element 50D of type "D" that has a different electrical configuration, to generate a selected electrical arrangement of the components on the three substrates 12. Those skilled in the art will appreciate that other shaped interconnecting elements can be substituted with no loss of functionality. Also, the interconnecting element or plug does not necessarily have to be separate from the substrates. That is, integral plugs can be formed on, for example, opposing sides of the substrate and configured to closely fit with the connectors or sockets of adjacent substrates.

[0056] Because the interconnecting element 50A in one embodiment is structurally symmetric but not necessarily electrically symmetric, the interconnecting element 50A includes an orientation key 58 that indicates the electrical orientation. The interconnecting element 50A also has an identifying mark "A" 60 indicating that it is a type "A" interconnecting element 50A. Of course, other marks, a color coding scheme, or the like can also be used to identify the interconnecting element type. For example, a colored band (not shown) can be asymmetrically placed on the interconnecting element 50A, in which the color correlates with the interconnecting element type and the asymmetric placement provides an orientation key.

[0057] With reference now to FIGURES 8A through 11B, four exemplary electrical configurations for interconnecting and terminating elements are described. The exemplary electrical configurations are described with reference to the electrical configuration of the substrate shown in FIGURES 3 and 5 in which each substrate 12 has two series-connected LED components 14a, 14b thereon. Furthermore, the interconnecting and terminating elements are configured using the conductor element 4 as the circuit ground.

[0058] With particular reference now to FIGURES 8A and 8B, a series interconnection of

two such substrates 12 is described. The pre-selected series electrical configuration is shown in FIGURE 8A . An interconnecting element 50S electrically connects the conductor member 5 of a first substrate 12 with the conductor member 1 of a second substrate 12 to effectuate a series interconnect. Additionally, the ground conductor members 4 are connected to provide ground continuity across the substrates 12 . As shown in FIGURE 8B , this corresponds to the illustrated interconnecting element 50S in which the conductor member 5' of the first port 52S is electrically connected with the conductor member 1' of the second port 54S to effectuate the series interconnection, and the conductor member 4' of the first port 52S is electrically connected with the conductor member 4' of the second port 54S to maintain ground continuity.

[0059] With particular reference now to FIGURES 9A and 9B , a parallel interconnection of two substrates 12 is described. The pre-selected parallel electrical configuration is shown in FIGURE 9A . An interconnecting element 50P electrically connects the conductor member 1 of a first substrate 12 with the conductor member 1 of a second substrate 12 , and interconnects the conductor member 5 of the first substrate 12 with the conductor member 5 of the second substrate 12 , to effectuate the parallel interconnect. Additionally, the conductor member 4 of the first substrate 12 is interconnected with the conductor member 4 of the second substrate 12 to effectuate ground continuity across the substrates. As shown in FIGURE 9B , this corresponds to the illustrated interconnecting element 50P in which the conductor member 1' of the first port 52P is electrically connected with the conductor member 1' of the second port 54P , the conductor member 5' of the first port 52P is electrically connected with the conductor member 5' of the second port 54P , and the conductor member 4' of the first port 52P is electrically connected with the conductor member 4' of the second port 54P .

[0060] With particular reference now to FIGURES 10A and 10B , a terminating element 50T is shown. The terminating element 50T is appropriate, for example, for terminating one or more series- or parallel-interconnected substrates 12 . An electrical schematic showing the operation of the terminating element 50T is shown in FIGURE 10A . The terminating element 50T electrically connects the conductor member 5 of the last substrate 12 to the circuit ground conductor member 4 . As shown in FIGURE 10B , this

corresponds to the illustrated terminating element 50T which has only a single port 52T that has its conductor member 5' electrically connected with the conductor member 4' to effectuate the grounding of the conductor member 5'.

[0061] With particular reference now to FIGURES 11A and 11B, a terminating element 50V providing electrical power to a circuit assembly is described. The terminating element 50V is appropriate, for example, for connecting one or more series- or parallel-interconnected substrates 12 to a source of electrical power. The electrical configuration is shown in FIGURE 11A. The terminating element 50V electrically connects the conductor member 1 to the positive terminal of an associated voltage source V, and also connects the ground conductor member 4 to the negative terminal of the associated voltage source V. As shown in FIGURE 11B, this corresponds to the illustrated terminating element 50V which has only a single port 54V. The conductor member 1' is electrically connected with the positive terminal of the associated voltage source V, while the conductor member 4' is electrically connected to the negative terminal of the associated voltage source V. In one embodiment, the terminating element 50V connects to the associated voltage source V through an electrical cable 64 that is disposed between the terminating element 50V and the voltage source V. Of course, other electrical connecting and transmission elements can also be included, such as a jack (not shown) that detachably connects the cable 64 to the terminating element 50V, and/or a jack (not shown) that detachably connects the cable 64 to the voltage supply V.

[0062] Other interconnecting and terminating elements are also contemplated. For example, a "null" interconnecting element (not shown) having no electrical interconnections therein can be provided. Such a "null" connecting element advantageously provides structural support to the modular mounting assembly without including corresponding electrical interconnections. It will also be recognized that the specific electrical configurations of the interconnecting elements depend upon both the selected electrical interconnection and on the electrical configuration of the substrate. The exemplary interconnecting and terminating elements of FIGURES 8A through 11B are appropriate for the substrate 12 illustrated in FIGURES 3 and 5. Regardless of the electrical configuration, the mechanical configuration of the interconnecting elements is advantageously standardized to facilitate formation of

complex modular mounting structures such as the hexagonal structure 10 of FIGURE 1.

[0063] In one aspect of the invention, standardized substrates are provided on which components, such as LED components, can be affixed. These substrates in combination with standardized interconnecting and terminating elements together cooperate to form selected modular interconnections of LED components. The interconnecting and terminating elements can advantageously include orientation key marks 58 and type indicators 60 to avoid misconnection. Although symbolic type indicators are shown in exemplary FIGURES 6 and 7, other type indicators such as color coding schemes are also contemplated. The ports 52, 54 also can be orientationally keyed (not shown) to further reduce the possibility improperly interconnecting the substrates comprising the modular mounting assembly.

[0064] With reference now to FIGURE 12, an exemplary assembly of six LED components on three substrates 12 is shown. Power is supplied from the voltage source V via a terminating element 50V. The three substrates 12 are interconnected using two series interconnecting elements 50S. The series string is terminated by a terminating element 50T', which differs from the terminating element 50T of FIGURES 10A and 10B in that an electrically unconnected second port is included to provide improved structural integrity. Although the extra port of terminating element 50T' is shown as completely electrically unconnected, in another contemplated embodiment the ground terminals 4' of the two ports are interconnected to provide additional ground continuity. In yet another contemplated embodiment (not shown) the terminating element 50T' is replaced by a completely electrically unconnected interconnecting element that has no electrical interconnections and provides only structural support to the modular mounting, and a connector of type 50T is connected to one of the unpaired ports of the last substrate 12 in the electrical series to provide the electrical termination.

[0065] The illustrated modular configuration of FIGURE 12 can be converted to a configuration having the three substrates 12 in parallel with the two LED components 14a, 14b of each substrate 12 connected in series by simply replacing the two series interconnecting elements 50S with corresponding parallel interconnecting elements

50P. The exemplary circuit shown in FIGURE 12 is rather simple. However, it will be appreciated that highly complex modular assemblies including dozens, hundreds, or even greater numbers of LED components having complex spatial arrangements, electrical interconnections, electrical sub-circuits, and the like can be created by appropriate selection and arrangement of a standardized set of substrates, interconnecting elements, and terminating elements. Another advantage of the present invention is that replacement of a failed LED component is greatly simplified, and requires only replacement of the substrate on which the failed LED component is disposed.

[0066] With reference now to FIGURES 13 and 14, another embodiment of the modular mounting assembly is described. A substrate 12RGB has six LED components arranged thereon: a first red LED component 14aR, a first green LED component 14aG, and a first blue LED component 14aB arranged in a first receiving well 22a; and a second red LED component 14bR, a second green LED component 14bG, and a second blue LED component 14bB arranged in a second receiving well 22b, as shown. The first and second LED component of each color is connected in series by PC board traces 40R, 40G, and 40B. In order to accommodate the greater number of anode and cathode terminals in this tri-color substrate 12RGB, connectors 16RGB having seven conductor members each is used. As shown in the electrical schematic of FIGURE 14, each of the three colors is independently addressable: conductor members 1 and 4 connect to the red LED series; conductor members 2 and 5 connect to the green LED series; and conductor members 3 and 6 connect to the blue LED series. The conductor member 7 serves as circuit ground in the substrate 12RGB. For substrates having more complex interconnections such as those shown in FIGURES 13 and 14, two-level or even more complex PC boards can be used to accommodate the larger number of traces involved.

[0067] It will be appreciated by those of ordinary skill in the art that the substrates comprising a modular mounting assembly need not have identical components arranged thereon, as long as the connectors are electrically and structurally compatible. Thus, for example, substrates having low intensity LED components (not shown) and substrates having high intensity LED components (not shown) can be intermixed in an array to form a dual-intensity lamp. Because the electrical

characteristics of LED components of different intensities often differ, and because it can be desirable to independently address the low intensity LED and the high intensity LED sub-arrays, different electrical conductor members can be advantageously used for the different LED intensities. Thus, for example, in a five-conductor connector, conductors 1 and 2 can be used for the low intensity LED interconnects, conductors 3 and 4 can be used for the high intensity LED interconnects, and conductor 5 can be used as the system ground. The substrates having only high intensity LED components advantageously have the conductor members 1 of the various connectors interconnected on the substrate, and similarly the conductor members 2 of the various connectors are advantageously interconnected, whereby electrical continuity for the low intensity sub-circuit is provided across the modular assembly. Similarly, the high intensity conductor members 3 and 4 of the connectors are advantageously interconnected, respectively, on the substrates having only low intensity LED components.

[0068] In another contemplated variation, blank substrates, e.g. substrates having no components thereon, can advantageously be used as placeholders in the modular assembly. Once again, like electrical conductor members of the blank substrate connectors can be interconnected on the substrate to provide electrical continuity where necessary.

[0069] With reference now to FIGURES 15 and 16, yet another embodiment of the invention is described, that is particularly suitable for interconnecting LED components on a flexible cable or other linear element. Such "LED strings" can be used as flexible linear light sources. As shown in FIGURE 15, the embodiment includes a substrate 12C that is essentially similar to the substrate 12 shown in FIGURES 3 and 5, except that an additional vertically oriented connector 16C is included on the substrate 12C. As shown in FIGURE 16, the connector 16C advantageously connects to a power cable 70 to form the LED string. In order to maximize the modularity of the substrate 12C, the substrate optionally retains the edge connectors 16, so that the substrate 12C can be used either in a planar array assembly such as the hexagonal assembly 10 of FIGURE 1, or in a linear LED string assembly as shown in FIGURE 16. Of course, the connectors 16 can also be omitted from the substrate 12C to reduce manufacturing costs.

